

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background**

At present, there have been power plants that use biomass fuel to power their plants due to the fact that this type of fuel is inexpensive and is readily available. However, in terms of operation biomass plants are more complex than those plants running on fossil fuel. In the biomass power plant, gasifier is needed to convert biomass materials, such as palm-oil, corn and sugar cane into combustible gases, which is then fed into an engine to generate electrical power. In the gasifier, the biomass is burnt in a low-oxygen environment, resulting in the production of combustible gases which consist of Carbon Monoxide (CO), Hydrogen (H<sub>2</sub>) and traces of Methane (CH<sub>4</sub>) and some particulate. This mixture of gas is called the producer gas which can be used to run internal combustion engines (for both compression and spark ignition). Accumulation of the particulate however, will eventually harm the combustion engine. As such, a filter is needed to reduce the formation of this particulate and hence will prolong the life span of the combustion engine. There are three main types of filter namely dry filter, wet filter and moist filter, each type is meant for different function. The operational condition of the filter needs to be observed with for its optimum performance. It is known that the dry filter exhibits the lowest maintenance and fabrication cost (Eggen and Kraatz, 1976). For the gasifier, the filter used must have the capability to operate under high temperature.

## **1.2 Problem Statement**

As in other biomass, gasification of oil palm fronds will result in combustible gases, moisture content, dust content, tar content and ash. The combustible gas is used as the fuel to power up combustion engine. However the other products from the gasification process may damage the combustion engine (shorten the life of the combustion engine). The products that may damage the combustion engine are tar, ash, water vapor, and dust. For instance, the dust content contained in the gas will choke the internal combustion engine which will reduce the intake of the air and fuel. This will result in low efficiency of the engine and after some time the engine will stop due to lack of fuel and air. The other products that will contribute to the damage of combustion engine are the ash content. The content tends to deposit in the cylinder of the engine and creates slag effect, which will increase the friction between cylinders of the engine and increase the probability of failure due to wear. The tar content will also deposit in the carburetor and the intake valve, causing stickiness and troublesome operation (Rajvanshi, 1978). With the deposit of tar, more force is needed to overcome the resulting friction.

## **1.3 Objective**

The objective of the project is to develop a biomass product gas cleaning system that can filter particulates from an oil-palm frond gasifier for use in internal combustion engines.

## **1.4 Scope of Study**

The project involves review of previous research about filtering of syngas from gasification process. The filter is designed and fabricated after simulation using CFD software. The study also involves series of testing and experiment of the filter.

## **CHAPTER 2**

### **LITERATURE REVIEW**

The definition of gasification process is the total or partial transformation of solid fuel component into gases. The gasification process usually been accomplished by thermal treatments or chemicals reaction, or a combination of both. Gasification is used to produce combustible gas which will then generate power from the combustion engine. The normal biomass products for gasification are corn cobs, coconut shell, bean straw barley straw, wood chips and many more (Rajvanshi, 1978).

#### **2.1 Gasification Process**

The gasification processes are divided into two parts which is devolatilization and also the combustion. In the usual context of thermal, gasification reactions are the one that takes place between the char or devolatilized solid fuel and gas excluding oxygen (Lee, 1996). It is almost impossible to have combustion without other reactions typical of gasification. For example, most fuel has hydrogen compound where this will form water during combustion which will react with carbon.

There is an immense number of gasification reactions. Nonetheless the most important are:

- Carbonaceous solid and water. In simplified notation,  $C + H_2O = CO + H_2$ . Therefore, if the aim is the production of fuel gases, this is one of the most important reactions.
- Carbonaceous solid and carbon dioxide, or simply  $C + CO_2 = 2CO$
- Carbonaceous solid and hydrogen, or simply  $C + 2H_2 = CH_4$

The other compound would involve as reactants and product because any usual carbonaceous fuel contains H, N, O, S, ect. Most of the species from the gasification reactions are at their reduced or less-oxidized forms, such as CO instead of CO<sub>2</sub>, H<sub>2</sub> instead of H<sub>2</sub>O, H<sub>2</sub>S instead of SO<sub>2</sub>, and NH<sub>3</sub> instead of NO (Lee, 1996).

Combustion is a gasification process where oxygen is present among the gases in contact with the fuel. The main combustion reaction is between carbon and oxygen, leading to carbon monoxide and dioxide. Temperatures typically found in combustion processes, practically only carbon monoxide is produced from the reaction. Carbon dioxide would be a typical product just at a relatively low temperature (Lee, 1996).

## **2.2 Gasifier Fuel Characteristics**

Almost any carbonaceous or biomass fuel can be gasified under experimental or laboratory conditions (Kaupp, 1982). However the real test for a good gasifier is not whether a combustible gas can be generated by burning a biomass fuel with 20-40% stoichiometric air but that a reliable gas producer can be made which can also be economically attractive. Towards this goal the fuel characteristics have to be evaluated and fuel processing must be done. A gasifier is very fuel specific and it is tailored around a fuel rather than the other way round. Thus a gasifier fuel can be classified as good or bad according to the following parameters:

- 1) Energy content of the fuel
- 2) Bulk density
- 3) Moisture content
- 4) Dust content
- 5) Tar content
- 6) Ash and slagging characteristic

The following parameter will elaborate more, where it is known to damage or reduce the performance of internal combustion engine.

### **2.2.1 Moisture Content**

In most fuels there is very little choice in moisture content since it is determined by the type of fuel, its origin and treatment. It is desirable to use fuel with low moisture content because of heat loss due to its evaporation before gasification is considerable and the heat budget of the gasification reaction is impaired. For example, for fuel at 25°C and raw gas exit temperature from gasifier at 300°C, 2875 kJ/kg moisture must be supplied by fuel to heat and evaporate moisture (Kaupp and Goss, 1981). Besides impairing the gasifier heat budget, high moisture content also puts load on cooling and filtering equipment by increasing the pressure drop across these units because of condensing liquid. Generally desirable moisture content for fuel should be less than 20% (when drying).

### **2.1.2 Dust Content**

All gasifier fuels produce dust. This dust is a nuisance since it can clog the internal combustion engine and hence has to be removed. The gasifier design should be such that it should not produce more than 2-6 g/m<sup>3</sup> of dust (Kaupp, 1982). The higher the dust produced, the more load is put on filters necessitating frequent flushing and increased maintenance (Breag and Chittenden, 1979).

### **2.2.3 Tar Content**

Tar is one of the most unpleasant constituents of the gas as it tends to deposit in the carburetor and intake valves causing sticking and troublesome operations (Skov and Paperworth, 1974). It is a product of highly irreversible process taking place in the pyrolysis zone. The physical property of tar depends upon temperature and heat rate and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water) (Kaupp, 1982). There are approximately 200 chemical constituents that have been identified in tar so far. Very little research work has been done in the area of

removing or burning tar in the gasifier so that relatively tar free gas comes out. Thus the major effort has been devoted to cleaning this tar by filters and coolers. A well-designed gasifier should put out less than 1 g/m<sup>3</sup> of tar. Usually it is assumed that a downdraft gasifier produces less tar than other gasifiers. However because of localized inefficient processes taking place in the throat of the downdraft gasifier, it has not allowed the complete dissociation of tar (Kaupp, 1982). More research effort is therefore needed in exploring the mechanism of tar breakdown in downdraft gasifiers. Shown in Figure 2.1 is the emission of tar in common biomass products. Since there are no data found on oil palm fronds, the emission of tar can be assume as the highest value of this biomass.

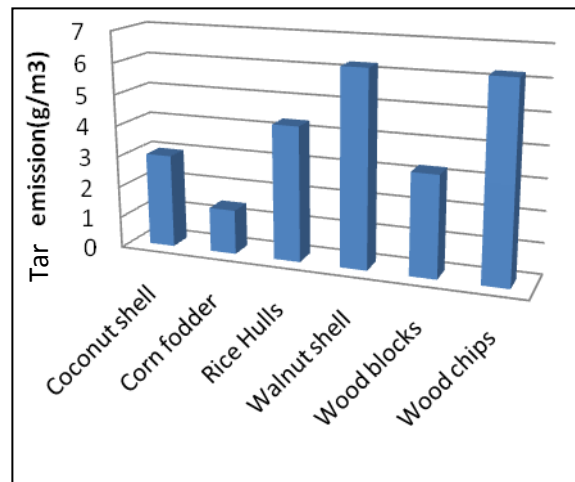


Figure 2.1: Chart on tar emission vs type of product (Nimbkar Agricultural Research Institute, 1982)

#### 2.2.4 Ash and Slagging Characteristics

The mineral content in the fuel that remains in oxidized form after complete combustion is usually called ash. The ash content of a fuel and the ash composition has a major impact on trouble free operation of gasifier.

Ash basically interferes with gasification process in two ways:

- a) It fuses together to form slag and this clinker stops or inhibits the downward flow of biomass feed.
- b) Even if it does not fuse together it shelters the points in fuel where ignition is initiated and thus lowers the fuel's reaction response.

Ash and tar removal are the two most important processes in gasification system for its smooth running. Various systems have been devised for ash removal. In fact some fuels with high ash content can be easily gasified if elaborate ash removal system is installed in the gasifier (Kaupp, 1982). Figure 2.2 shows the emission of ash in other biomass product. Since there are no data found on oil palm fronds, the emission of ash can be assume as the highest value of this biomass.

Slagging, however, can be overcome by two types of operation of gasifier:

- 1) Low temperature operation that keeps the temperature well below the flow temperature of the ash.
- 2) High temperature operation that keeps the temperature above the melting point of ash.

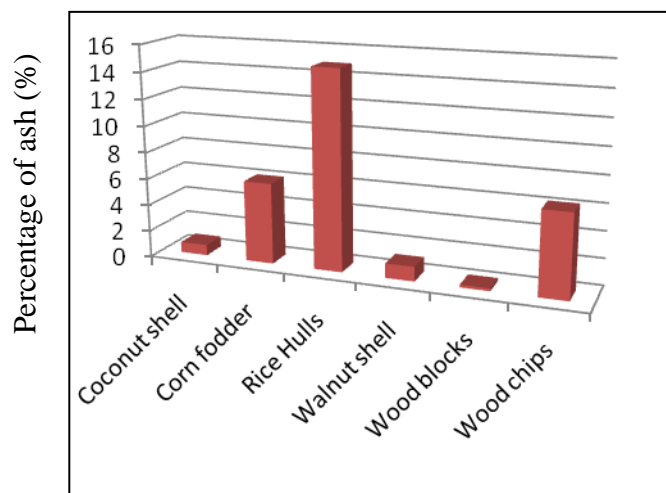


Figure 2.2: Chart on percentage of ash emission vs type of product (Nimbkar Agricultural Research Institute, 1982)

Table 2.1: Data on product and its emission (Nimbkar Agricultural Research Institute, 1982)

Fuel	Tar produce (g/m <sup>3</sup> )	Ash content (%)
Coconut shell	3.00	0.8
Corn fodder	1.43	6.1
Rice hulls	4.32	14.9
Walnut shell	6.24	1.1
Wood blocks	3.24	0.2
Wood chips	6.24	6.26

The data that has been gathered are based on the Nimbkar agricultural Research Institute. The data had been put in table form as shown in Table 2.1. Base on data the number of tar and ash emission of oil palm frond are the max number that can get that is 6.24 g/m<sup>3</sup> for tar emission and 14.9 % of ash emission since there is no collected data for the gasification product of oil palm frond. It is decided that to take the highest value of the tar produce and ash content, as for the capacity of the filter.



## 2.3 Types of Filter

Basically there are three major types of filter that is dry type filter, moist type filter and also wet type filter. All types of filter have their advantages and disadvantages. The requirement of the system will determine on what type of process that is crucial to the flow; for example some system may not tolerate with much of pressure drop in the system therefore they will need a type of filter that does not do much pressure drop (Green Force, 2008).

### 2.3.1 Dry Filter, (Cyclone – Dynamic Separators)



Figure 2.3: Cyclone – Dynamic separators (Green Force, 2008)

Figure 2.3 shows cyclone filter for filtering dust from the truck exhaust. As shown in the figure, the cyclone removes the particulates by causing the dirty airstream to flow in a spiral path inside a cylindrical chamber. Dirty air enters the chamber from a tangential direction at the outer wall of the device, forming a vortex as it swirls within the chamber. The larger particulates, because of their greater inertia, move outward and are forced against the chamber wall. Slowed by friction with the wall surface, they then slide down the wall into a conical dust hopper at the bottom of the cyclone. The cleaned air swirls upward in a narrower spiral through an inner cylinder and emerges from an

outlet at the top. Accumulated particulate dust is periodically removed from the hopper for disposal.

Cyclones are best at removing relatively coarse particulates. They can routinely achieve efficiencies of 90 % for particles larger than about 30  $\mu\text{m}$ . By themselves, however, cyclones are not sufficient to meet stringent air quality standards. They are typically used as precleaners and are followed by more efficient air-cleaning equipment such as electrostatic precipitators and baghouses.

Dynamic separators work on gravitational and inertial force as to mechanical separation. The form of separation is by settling, which relies purely on gravitational force separation of solid from a fluid which there are suspended. A particle will reach its settling velocity when the drag force and buoyancy force balance with the gravitational force on the particle.

$$\text{Settling velocity} \propto \frac{\rho d}{v} \quad (2.1)$$

where  $\rho$  is the particle density that been release from the gasification process while  $d$  is the particulate diameter, and  $v$  is flow velocity. As for the equation of settling velocity ( $V_s$ ) under the present of gravity are shown below:

$$V_s = \frac{d^2 \times (\Delta_1 - \Delta_2)}{Kv} \times g \quad (2.2)$$

where  $\Delta_1 - \Delta_2$  is the difference in densities of the particle and the fluid,  $g$  is the gravity and the  $K$  is the constant depending on “ $d$ ” and “ $v$ ”

From Equation 2.2 the most contribute to the settling velocity are the particle diameters and followed by the fluid velocity, since the particle size are in microns therefore the square of it will only make it smaller. As for the fluid velocity it also contributes to the settling velocity where the higher the fluid velocity the lower the settling velocity it will be, which means the particle are in the vortex and not near the wall of the cyclone filter.

As for the presences of the dynamic forces in the cyclone filter for example the present of a centrifuge blower or compressor are shown below:

$$V_s = \frac{d^2 \times (\Delta_1 - \Delta_2)}{Kv} \times f \quad (2.3)$$

In the Equation 2.3,  $f$  , centrifugal acceleration, can also be represented as  $R\omega^2$ , where R represents the effective radius of centrifuge and  $\omega$  is the angular relationship between particle density, diameter and fluid flow.

### 2.3.1.1 Type of Cyclone Filter

The cyclone filter can be divided into 3 categories or model. In this 3 model the height in cylinder and also the cone are varied. The height of cylinder and cone are been vary to suit the requirement of the system. The 3 types of model are shown in Figure 2.4:



Figure 2.4: Types of cyclone filter

a) Model K

Model K cyclone separator which are used in applications where large particles exist like chips or shavings. Model K does this when the speed of the dust filled air stream is slowed down, heavier dirt particles settle down from the air stream by gravity and fall into a hopper where they are collected. Large diameter cyclones can handle high dust loads (50-100 grains per cu.ft) with low pressure drops (1.5 to 3 inch) efficiently. Model K is also used when height restrictions pose as a problem (Ress, 2009)

b) Model KL

Model KL is similar to the Model K but with a longer cone section that is used where efficiency is needed for mixtures of finer particles. Also with a longer cone body, the separator has the ability to breakdown particles to low level microns (30  $\mu\text{m}$  - 40  $\mu\text{m}$ ) (Ress, 2009).

c) Model RHV

Model RHV separators are used in applications involving finer dust particles (20  $\mu\text{m}$  - 30  $\mu\text{m}$ ), or more abrasive materials (Ress, 2009).

### 2.3.1.2 Sizing of Cyclone Filter

Models RHV are selected because of its characteristic which involves fine particulate. Therefore the equations to size the cyclone filter are based on the RHV model. In cyclone filter sizing there is 5 major calculations needed to be done in order to size the cyclone filter. First is the diameter cut where it is the cyclone diameter of the cylinder then followed by the inlet height, inlet width, cylindrical length, and also the cone length:

Diameter cut;

$$d_{cut} = \sqrt{\frac{9 u_{gas} W}{2\pi N v_{inlet} (p_{particulate} - p_{gas})}} \quad (2.4)$$

Inlet height;

$$h = \frac{\pi}{N} (2L_{cylinder} + L_{cone}) @ h = \frac{d_{cut}}{2} \quad (2.5)$$

Inlet width;

$$W = \frac{2\pi d_{cut}^2 N v_{inlet} (p_{particle} - p_{gas})}{9 u_{gas}} \quad (2.6)$$

Cylinder length;

$$L_{cylinder} = \frac{1}{2} \left( \frac{Nh}{\pi} - L_{cone} \right) \quad (2.7)$$

Cone length;

$$L_{cone} = \frac{Nh}{\pi} - 2L_{cylinder} \quad (2.8)$$

All the formulas in sizing the cyclone is shown above and all the symbols are  $p_{\text{particle}}$  is the particle or particulate density,  $p_{\text{air}}$  is the air density,  $p_{\text{gas}}$  is the gas density,  $\mu$  is the air viscosity,  $\mu_{\text{gas}}$  is the gas viscosity,  $N$  is the approximate effective turns,  $h$  is the inlet height,  $L_{\text{cylinder}}$  is the cylinder length,  $L_{\text{cone}}$  is the cone length,  $d_{\text{cut}}$  is the cut diameter, which is also the diameter of the cyclone's cylinder and,  $W$  is inlet width. For the proportion of short

Figure 2.5 shows the diagram of the cyclone filter and the dimension to illustrate towards the formula.

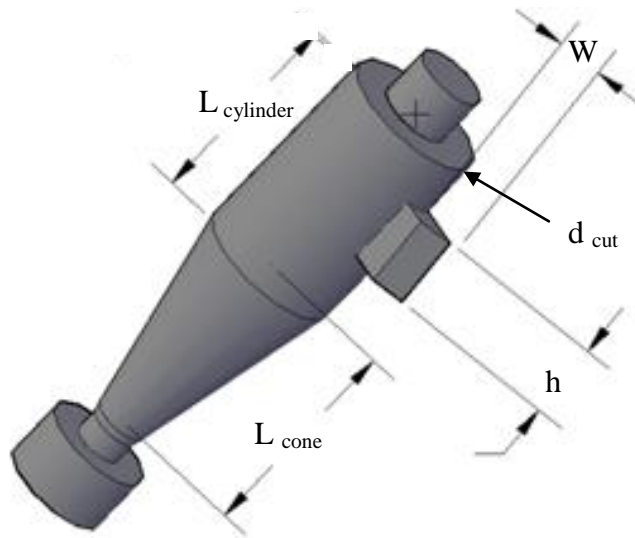


Figure 2.5: Cyclone filter and the dimension

### 2.3.2 Wet Filter

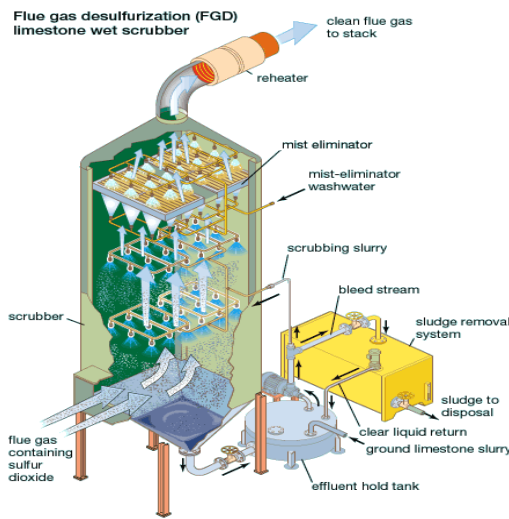


Figure 2.6: Wet filter (Green Force, 2008)

Several configurations of wet scrubbers as for the in Figure 2.6 are spray-tower scrubber; an upward-flowing airstream is washed by water sprayed downward from a series of nozzles. The water is recirculated after it is sufficiently cleaned to prevent clogging of the nozzles. Spray-tower scrubbers can remove 90% of particulates larger than about 8  $\mu\text{m}$  (Green Force, 2008).

In orifice scrubbers and wet-impingement scrubbers, the air and droplet mixture collide with a solid surface. Collision with a surface atomizes the droplets, reducing droplet size and thereby increasing total surface contact area. These devices have the advantage of lower water-recirculation rates, and they offer removal efficiencies of about 90% for particles larger than 2  $\mu\text{m}$  (Green Force, 2008).

Venturi scrubbers are the most efficient of the wet collectors, achieving efficiencies of more than 98% for particles larger than 0.5  $\mu\text{m}$  in diameter. Scrubber efficiency depends on the relative velocity between the droplets and the particulates. Venturi scrubbers achieve high relative velocities by injecting water into the throat of a venturi channel (a constriction in the flow path) through which particulate-laden air is passing at high speed (Green Force, 2008).

## CHAPTER 3

### METHODOLOGY

#### 3.1 Overview

The project has a work flow as shown in Figure 3.1. The project first started in overview study of biomass gasification must be studied (the output of the gasifier) by identifying the characteristics of the resulting particles. The acceptable range of particulate content for the engine will also be studied. The study on understanding the particulate that will harm the combustion engine are more towards the literature reviews.

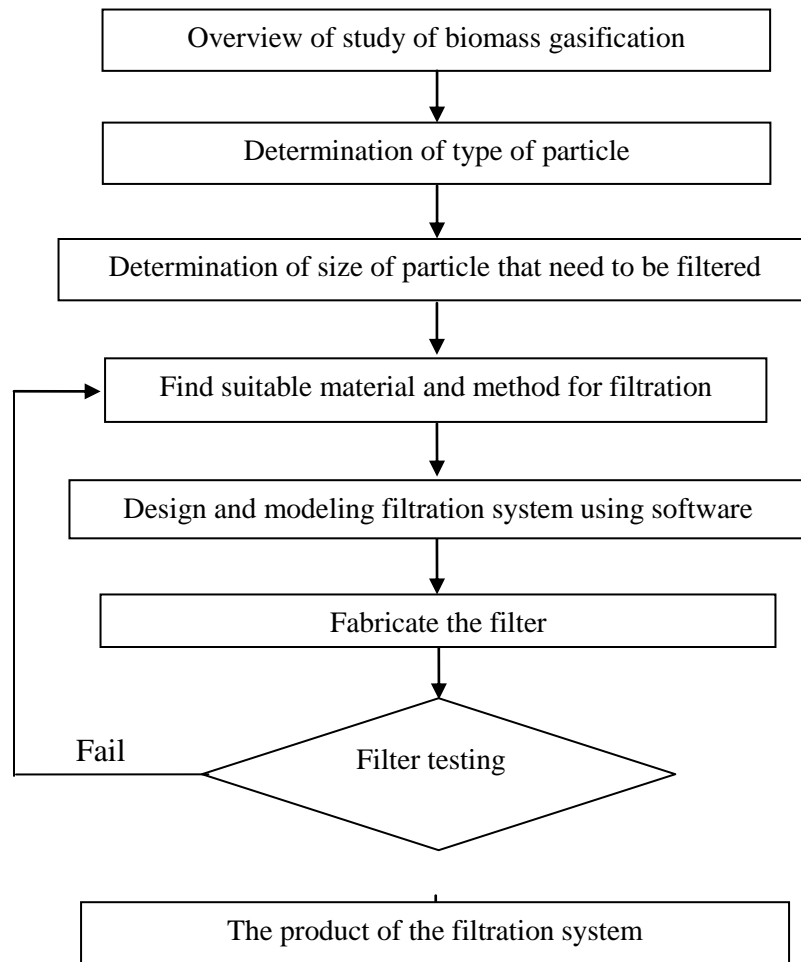


Figure 3.1: Work flow



The suitable material and method for filtering have been identified based on the gasifier output conditions, the particle size that is needed to be filtered based on the reading materials that have been studied. Ranges of filtering systems available in the market have been studied for comparison. After the study on the filtering system some calculations are needed to be done to design the filtering system. The filter has been designed with the aid of software called AutoCAD. The fabrication are been done by outsourcing to the manufacture. The last stage of the project is to test the filtering system.

### 3.2 Gantt Chart

It is very important to have Gantt chart to gauge the progress of the project. The Gantt chart shows the expected tasks that need to be completed within the time line estimated. The Gantt chart there is divided into two major sections which is the task and also the week to achieve it. In the time slot there are also been differentiate in colours. Blue in colour mean that is the overall time slot for the main section. The colour of green represented the time line for the specific task. Lastly the maroon colour represent the submission due date.

Table 3.2: Gantt Chart for FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	<b>Selection of Project Topic</b>														
	-Propose Topic														
	-Topic assigned to students														
2	<b>Preliminary Research Work</b>														
	-Introduction														
	-Objective														
	-List of references/literature														
3	<b>Project planning</b>														
4	Submission of Preliminary Report														
5	<b>Project Work</b>														
	-Reference/Literature														
	- Gasification process														
	- Identifying product of gasification														
	- identifying product that damage combustion engine														
	- identifying type of filtration														
	- implementing filtration														
6	<b>Submission of Progress Report</b>														
7	<b>Project work continue</b>														
	-Practical/Laboratory Work														
8	<b>Submission of Interim Report</b>														
9	<b>Oral Presentation</b>														

Table 3.3: Gantt Chart for FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	<b>Laboratory work</b>														
	-Acquiring approval														
	-Designing prototype														
	-Collecting data														
	-Vendor survey														
	-Fabrication														
	-Testing														
	-Data gathering														
2	<b>Paper Work</b>														
	Submission of Preliminary Report														
	Submission of final Report														
	Oral Presentation														

### 3.3 Selection of Filter

For selecting the type of filter, there are some considerations that needed to be taken into account such as the engineering side which is the material selection efficiency of the filter, machining cost, maintenance cost. As for the least maintenance cost are in the dry type filter and the filter is the cyclone filter where it is the lowest maintenance cost in the filter type. This is because there is only needed to remove the particulate at the settling tank. Compare to other type of filters (fabric) where there is a need to wash or replace the filter. However, the cyclone filter is just only the part of the filtering system, since it only removes up to 20 $\mu$ m - 30 $\mu$ m, there will be other filters that will placed after the cyclone filter.

By going through those three models of cyclone filter in chapter 2 the model RHV is selected, it is because after the gasification process it will produce a fine particle that is smaller than 30 $\mu$ m. therefore it is in need to filter smaller particle. Other than that the product of the gasification may have abrasive product.

### 3.4 Design of Filter

All the dimensions of the cyclone filter are based on the software that are found in the internet. The design further has been checked by using manual calculations as shown in the Chapter 4. After the design has been doubled checked with the manual calculation, the cyclone filter is drawn by using AutoCAD. There are two parts contained in the cyclone filter which is the settling tank, and the cyclone filter itself. In the designing stage there is a need to integrate all the software together; there are three types of Computer Aided Design (CAD) software that are involved in this project. The software are AutoCAD, Gambit and also Fluent. As for AutoCAD it is been used to design the filter with accurate dimensions. In the drawing it can be converted into detail-drawings for fabrication purposes, and then the file is exported into ACIS format to be opened by Gambit. As for the next software which is the Gambit software it is used to mesh the volume of the filter so that it can be read by the next software to run the simulation process of the fluid flow. In other words, the Gambit Software is to make the interior of the filter as the volume so that the simulation can detect as a fluid to be analyzed. After the meshing process it then opened in software called Fluent 6.2. In this software the fluid simulation is done. The data output can be accurate provided that the input of the data such as the boundary condition the material is inserted accurately. Figure 3.2 shows the sample drawings of AutoCAD:

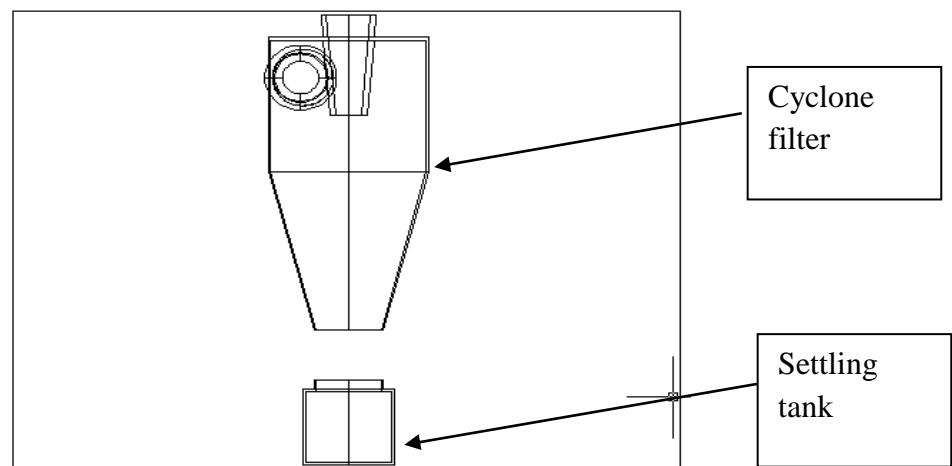
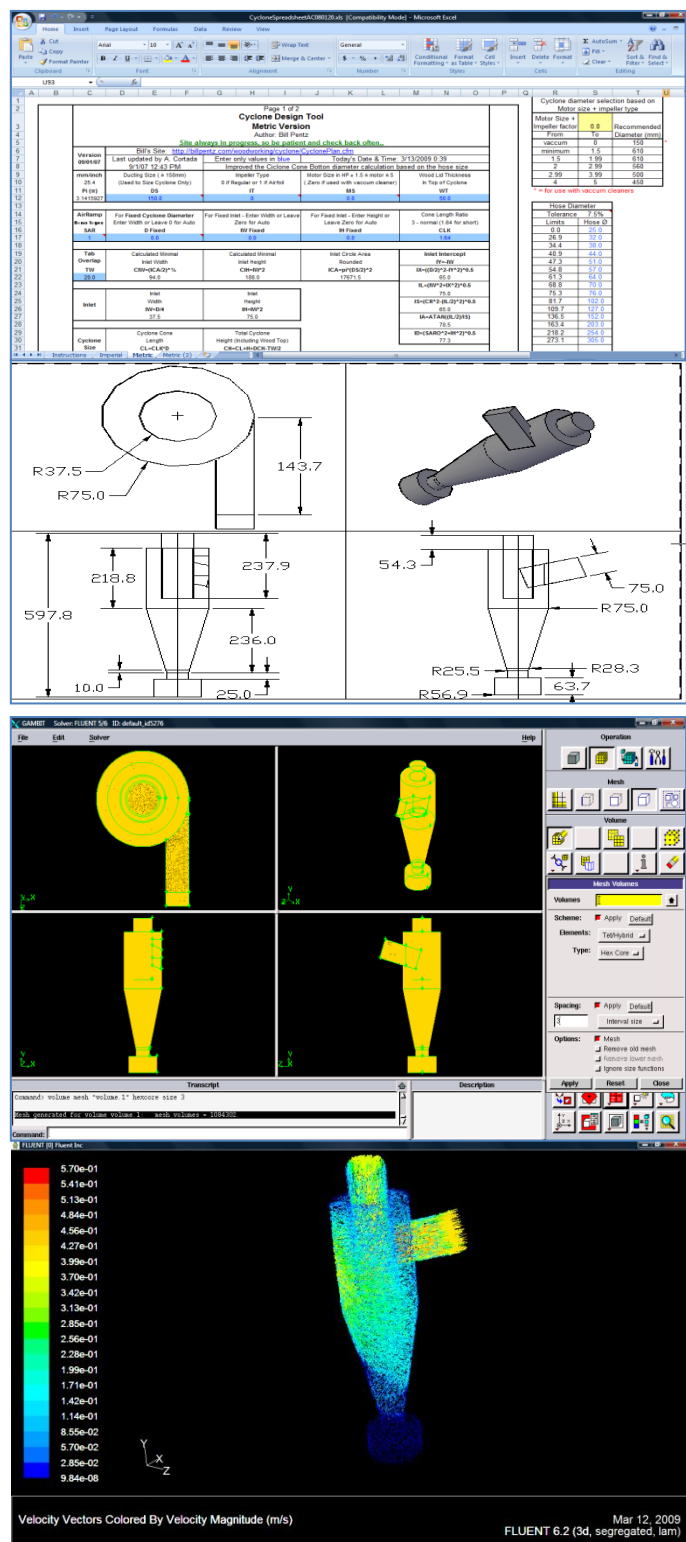
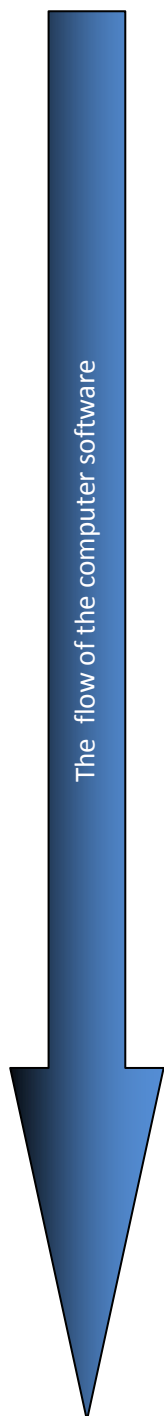


Figure 3.2: Front view of the cyclone filter settling tank been detach (AutoCAD software)

It is very important to verify the effect and also to check the design using simulations. The simulation will basically show the behavior of the particle that is gone through the filter. It is to check whether it behaves the same as the literature reviews that has been done. The importance of the simulation is that it shows the act of flow in the filter in the real conditions by giving accurate parameters needed. Figure 3.5 shows the step needed to integrate the software from designing in AutoCAD to the simulation stage in Fluent.



Designing software for cyclone filter according to velocity of the flow

Drawing of cyclone filter according dimension using AutoCAD.

Meshing of filter using Gambit software.

Simulation of flow in filter using Fluent software

Figure 3.3: The sequence of conducting the software (for details refer to appendix)

### 3.5 Software Parameters

Using the software there are requirements needed to be fulfilled in order to run the simulation process. First, from the normal drawing it is needed to be converted into ACIS so that it can be operated by Gambit software for meshing. Meshing is required in order to run the simulation with Computational Fluid Dynamics (CFD) analysis. The accuracy of the CFD analysis depends on the spacing between meshes. The smaller the size of the mesh, the more accurate the simulation or the analysis will be. As for the cyclones filter size of mesh that has been designed with the interval spacing of 3. In the Table 3.3 shows the parameters considered in the meshing:

Table 3.4: Meshing parameters for Cyclone Filter

Option of meshing	<ul style="list-style-type: none"><li>• Element = Tet/Hybrid</li><li>• Type = Hex core</li><li>• Interval size = 3</li></ul>
Mesh generated for volume	1084302
Boundary type	<ul style="list-style-type: none"><li>• Input velocity</li><li>• Outlet vent</li></ul>

After the meshing process in Gambit, it is needed to be transferred and saved in a mesh file to perform the simulation. In the simulation there are some inputs needed to be inserted in order to run the simulation. The parameters that are needed to be set are shown in Table 3.4.

Table 3.5: Parameters for the Flow inside the Cyclone

Viscous model	Laminar
Numbers of iteration	100000
Fluid	<ul style="list-style-type: none"> <li>• Ash</li> <li>• Hydrogen</li> <li>• Methane</li> <li>• Water vapor</li> </ul>
Inlet velocity	0.4132 m/s
Temperature	1000K

The inlet velocity that has been taken is 0.4132 m/s. This is because the value are been taken from the person who do the project on the gasifier (Hun, 2008). In the calculation the person get the value for the velocity output of the gasifier. The variation of the velocity profile in the designed cyclone filter is shown in the Appendices A-5 and A-6.

### 3.6 Material Selections

It is important to select the proper material for fabricating the filter because this is one of the factors contributing to the durability of the filter. In the material selection there are many aspects needed to be considered, for example the cost, melting point, able to-be-machine, mechanical properties and many more. According to the person who has done a project on gasifier development (Hun, 2008), the outlet temperature of the gasifier is about 400-700°C. The material for the filter should have higher melting point then 700°C. If a safety factor of two is taken, the melting temperature of the material will be 1400°C. In the material selection there are many aspects needed to be considered which is cost, melting point, able to-be-machine, mechanical properties and availability.

Table 3.6: List of properties of the material (Ress, 2009)

Elements	Symbol	Melting Point Celsius	Melting Point Fahrenheit
Aluminum	Al	659	1218
Brass (85 Cu 15 Zn)	Cu+Zn	900-940	1652-1724
Bronze (90 Cu 10 Sn)	Cu+Sn	850-1000	1562-832
Cast Iron	C+Si+Mn+Fe	1260	2300
Carbon	C	3600	6512
Chromium	Cr	1615	3034
Copper	Cu	1083	1981
Gold	Au	1063	1946
Hydrogen	H	-259	-434.2
Inconel	Ni+Cr+Fe	1393	2540
Iron	Fe	1530	2786
Lead	Pb	327	621
Magnesium	Mg	670	1240
Manganese	Mn	1260	2300
Monel	Ni+Cu+Si	1301	2400
Nickel	Ni	1452	2646
Phosphorous	P	44	111
Silicon	Si	1420	2588
Silver	Ag	961	1762
Stainless Steel	Cr+Ni+Mn+C	1363	2550
Steel-High Carbon	Cr+Ni+Mn+C	1353	2500
Medium Carbon	Cr+Ni+Mn+C	1427	2600
Low Carbon	Cr+Ni+Mn+C	1464	2700
Tin	Sn	232	450
Titanium	Ti	1795	3263
Tungsten	W	3000	5432
Zinc	Zn	419	786

The materials that have been short listed are stainless steel, iron and cast iron. All these materials have a melting point of above 1000 °C according to Table 3.6. Unintentionally, other factors are also achieved which include the ability to machine, mechanical properties, availability and also cost.

According to the basic estimation, stainless steel is preferred because it is already coated and therefore the surface is unlikely to corrode. The surface of stainless steel is also finer as compared to those of iron and cast iron. The surface of the material plays an important role in filtering and also in preventing obstacles for the flow.



### **3.7 Procedure of Testing**

To test the content of the gas produced after the gasification process, there are some methods can be used to detect ash content in the gas. The content of ash is measured by weight after time. The detail procedure is, first weight; the normal fabric filter, the second step; fire up the gasifier , the third step; is to wait for the gasifier to be stable with the gasification and the flow, then the fabric filter is assembled at the outlet of the gasifier, after 30 minutes, the filter is taken out and measured. Procedure for 3 to 5 is repeated to get the average value. The final weights are to be subtracted from the initial value of the filter to measure the content of the ash. As for tar, the same method can be used but some modification is needed to be done which the finest of the filter is needed to be change and also the gas released is needed to be contained to obtain the density of the emission.

## CHAPTER 4

### RESULT AND CALCULATION

#### 4.1 Identifying Type of Flow

The type of flow are been identify by using Reynolds equation, the Reynolds value is important to identifying the type of flow which is require in the Fluent software.

$$Re = \frac{\rho v d}{\mu} \quad (2.10)$$

where  $\rho$  is density of the fluid,  $v$  is the velocity of the fluid,  $d$  is diameter of the pipe and  $\mu$  is dynamic viscosity. Given that  $\rho$  is  $0.524473 \text{ kg/m}^3$ ,  $v$  is  $0.4132 \text{ m/s}$ ,  $d$  is  $0.048 \text{ m}$  and  $\mu$  is  $1.384 \times 10^{-5} \text{ kg/m.s}$ .

From the calculation the Reynolds number is 749, which mean the flows in the pipe are laminar. Therefore the data been put in the simulation (Fluent) will be in laminar type. The type of flow must be included in the simulation because the filters are working if there is the flow of the fluid.

#### 4.2 Verifying the Design using Calculation

For the diameter cut section, it is the diameter of cylindrical part of the cyclone filter (as shown in Figure 2.5). The diameter cut are been calculate with respect to the velocity of the flow, the density of particle and also the fluid. As for the inlet width of the cyclone filter it is just a quarter from the diameter cut of the cyclone filter.

#### 4.2.1 Diameter Cut

$$d_{cut} = \sqrt{\frac{9 u_{gas} W}{2\pi N v_{inlet} (p_{particulate} - p_{gas})}} \quad (2.4)$$

Given that N are range between 20 to 30 take 28,  $V_{inle}$  is 0.4132 m/s,  $p_{particulate}$  is 0.02 kg/m<sup>3</sup>,  $p_{gas}$  is 0.524473 kg/m<sup>3</sup>,  $u_{gas}$  is 2.61 and W is the with of the inlet or  $d_{cut}/4$ . The values are inserted in Equation 2.4. Therefore the value of  $d_{cut}$  is 0.15 m.

Therefore the value of  $d_{cut}$  is 0.15 m, W is given as:

$$\begin{aligned} W &= d_{cut} / 4 \\ &= 0.15/4 = 0.0375m \end{aligned}$$

#### 4.2.2 Inlet Height

As for the inlet height the equation is simply a half of the diameter cut. There is other formula in findings of the inlet height but there are some values that are not available in completing the equation.

$$h = \frac{\pi}{N} (2L_{cylinder} + L_{cone}) \quad (2.5)$$

Or

$$h = \frac{d_{cut}}{2}$$

Known that N is 28 and  $d_{cut}$  is 0.15m. There is unknown value for  $L_{cylinder}$  and  $L_{cone}$ , there fore used the equation below which will get the value of h is 0.075m

#### 4.2.3 Cylinder Length

Cylinder length is the cylinder height of the cyclone filter (Figure 2.5). As for the equation, the lengths of the cylinder are affected by the inlet height and also the length of the cone.

$$L_{cylinder} = \frac{1}{2} \left( \frac{Nh}{\pi} - L_{cone} \right) \quad (2.6)$$

Given h is 0.075m , N is 28,  $L_{cylinder}$  is 0.2188 m. after substituting the value the equation will be as shown below:

$$2L_{cylinder} + L_{cone} = 0.6685$$

Using the short dimension of the cyclone, the proportion of the  $L_{cylinder}$  to  $L_{cone}$  is 1: 1.124 therefore:

$$1.124L_{cylinder} = L_{cone}$$

Using the short dimension, do simultaneous equation;

$$2L_{cylinder} + 1.124L_{cylinder} = 0.6685$$

$$L_{cylinder} = 0.2188 \text{ m}$$

The length of the cylinder are already been calculated. Therefore the calculation can be proceeded to find the cyclone filter cone length.

#### 4.2.4 Cone Length

Cone length is the height of the cone section in the cyclone filter (Figure 2.5). The value of the cone length can be known by substituting the value in the equation.

(2.7)

$$L_{cone} = \frac{Nh}{\pi} - 2L_{cylinder}$$

Given  $L_{cyclone}$  is 0.2188 m, N is 28 and h is 0.075m. Therefore;

$$L_{cone} = \frac{28 \times 0.075}{\pi} - 2 \times 0.2188$$

$$L_{cone} = 0.246 \text{ m}$$

### 4.3 Dust and ash settling velocity

From Equation 2.2 the settling velocity of ash and dust can be calculated.

$$V_s = \frac{d^2 \times (\Delta_1 - \Delta_2)}{Kv} \times g \quad (2.8)$$

Given that  $g$  is  $9.81 \text{ m/s}$ ,  $d$  is  $30 \times 10^{-6} \text{ m}$ ,  $v$  is  $0.4132 \text{ m/s}$ ,  $\Delta_1$  is  $0.524473 \text{ kg/m}^3$  (from the ideal gas equation) and  $\Delta_2$  is  $0.002 \text{ kg/m}^3$

To get the density of the fluid (air) use ideal gas equation which is:

$$PV = mRT \quad (2.9)$$

Where it can further be simplified to get in density form and change the density as the determining equation as shown below.

$$\rho = P/RT$$

where  $P$  is the pressure of the air,  $\rho$  is the density of the air,  $T$  is temperature in Kelvin and  $R$  is constant. From that the value been plugged in and the density  $\rho$ , of the fluid are  $0.524473 \text{ kg/m}^3$

Back to settling velocity for dust, the value is been plugged in and the value of the settling velocity are  $2.2328 \times 10^{-7} \text{ m/s}$

For ash settling velocity,

The given data are  $\rho_{\text{ash}}$  is  $1.9 \text{ g/cm}^3$  which is equal to  $1900 \text{ kg/m}^3$  and  $d_{\text{ash}}$  is  $20 \text{ }\mu\text{m}$ . Using Equation 2.8 the value of settling velocity of ash are  $3.6077 \times 10^{-4} \text{ m/s}$

Therefore the dusts and ash will achieve its settling velocity at  $2.2328 \times 10^{-7} \text{ m/s}$  and  $3.6077 \times 10^{-4} \text{ m/s}$  therefore the cyclone filter must have variation of velocity until  $2.2328 \times 10^{-7} \text{ m/s}$  and  $3.6077 \times 10^{-4} \text{ m/s}$  to achieve the dust particle to have it equilibrium state towards drag force and applied force. Since the variation of the velocity in the simulation in Appendices A-5 varies from  $9.84 \times 10^{-8} \text{ m/s}$  to  $0.57 \text{ m/s}$  so the cyclone filter does filter the dust particle and also ash.

## CHAPTER 5

### DISCUSSION

#### 5.1 Simulation of Flow in Cyclone Filter

Other than the filter using the concept of settling velocity, the cyclone filter also uses the concept of inertia where the heavier particles tend to move further from the center thus having a contact with the wall of the cyclone and then reducing the velocity of the particle or product. When the particle loses its kinetic energy, it will fall and is collected at the settling tank. To study the velocity distribution in the cyclone filter, it is divided into three parts which are the top, middle and bottom sections as shown in Figure 5.1.

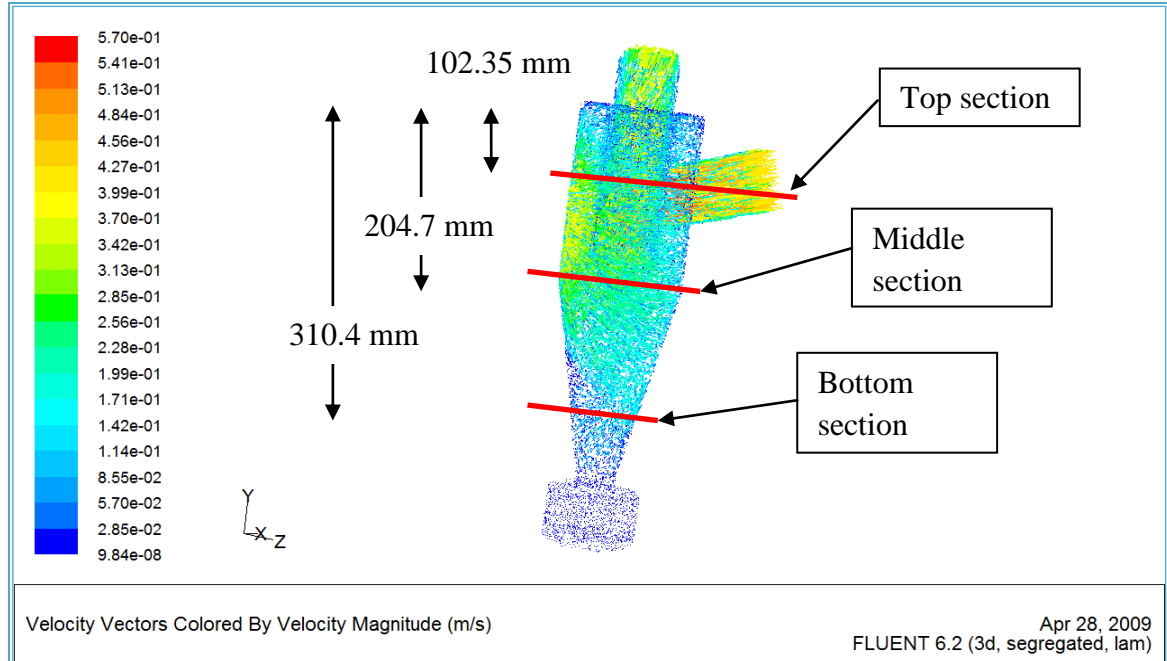


Figure 5.1: Section that been divided in three sections

##### 5.1.1 Top Section

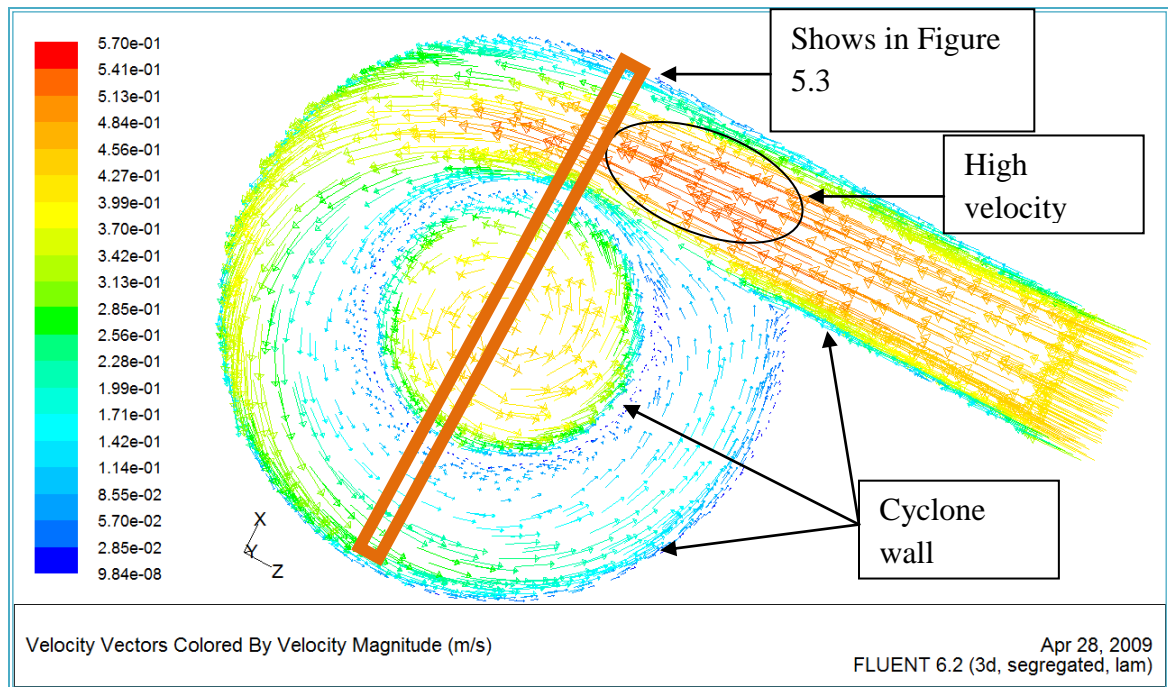


Figure 5.2: Horizontal top cross sectional cutting of cyclone filter

From Figure 5.2 it is shown that in the top section the velocity of the flow are in high velocity especially in the inlet flow. After certain distance the velocities of the flow become less. This is because of the frictional at the wall of the cyclone which will then affect the kinetic energy of the flow. In Figure 5.2 the velocity magnitude shows clearly that the lowest velocity flow is at the wall of the cyclone filter, which is range between  $2.85 \times 10^{-2}$  m/s to 0.199 m/s. At this stage the velocity variation still would not achieved the settling velocity of the large product from the gasification process which is dust and ash. The top section can be analyzed deeper as one section to study the velocity profile. The velocity profile that been highlighted in the orange box is shown in Figure 5.3.

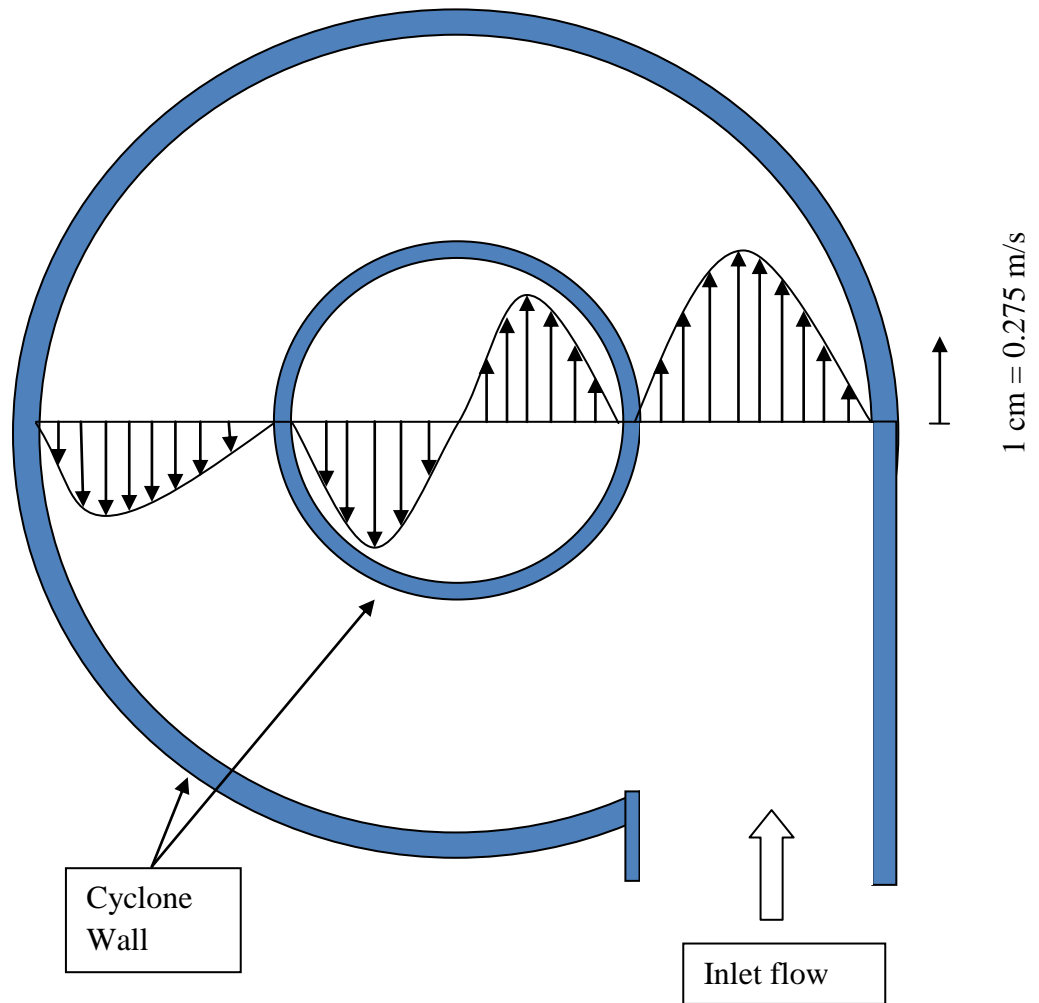


Figure 5.3: Velocity profile of top horizontal cross sectional of cyclone filter

Figure 5.3 shows the velocity profile in the top section area. In this velocity profile it is clearly shown that the velocity will have a decrease as it is nearer to the cyclone wall. At the most left velocity profile, the distributions of flow are not symmetric, this is because the inlet flow been redirected from the axial flow to radial flow. The fluid tends to be near to the wall, as result of inertia.



### 5.1.2 Middle Section

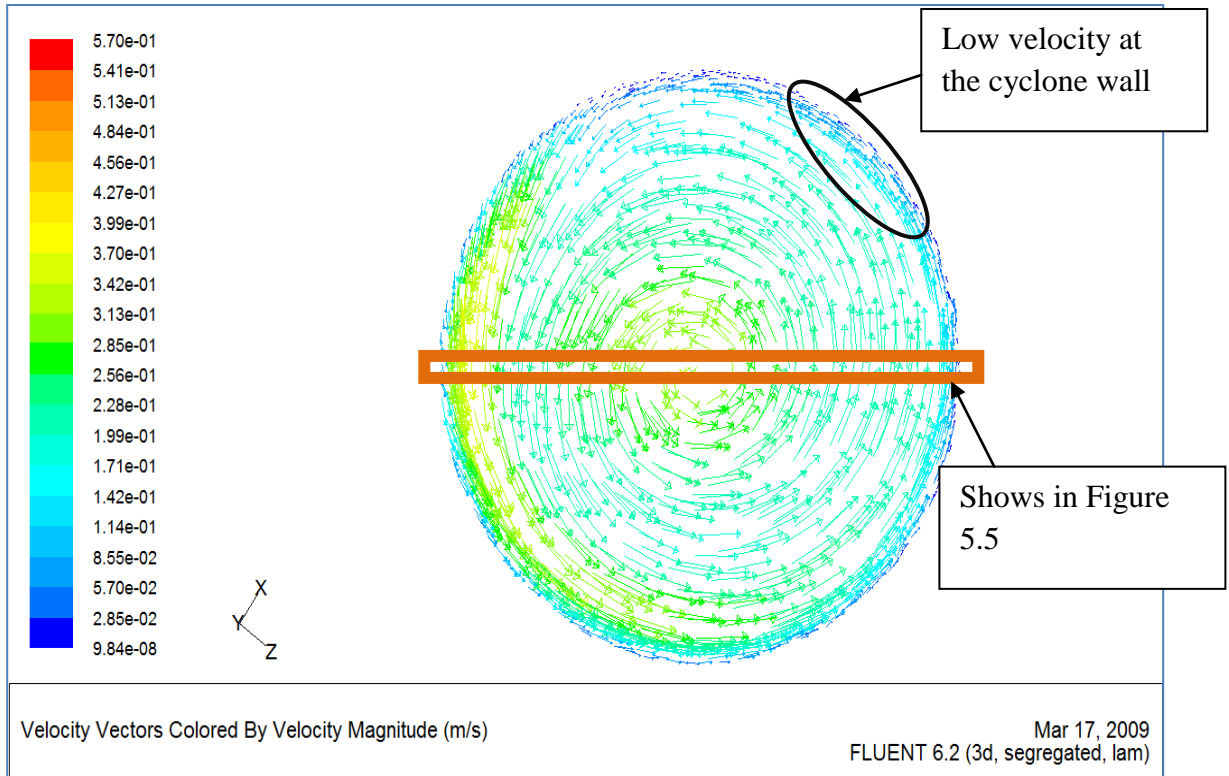


Figure 5.4: Horizontal middle cross sectional cutting of cyclone filter

In Figure 5.4 it is shown in the middle cross sectional of the cyclone filter that the velocity of the flow are not as high compare to the top section. Here the ranges of the velocity are from  $9.84 \times 10^{-8}$  m/s to  $3.70 \times 10^{-1}$  m/s. At this state the settling velocity of ash and dust are starting to take place. Some of the ash and dust are being at zero kinetic energy where by only the gravity will take effect on the particles which mean the particle will fall down to the settling tank. To see the cross sectional to be clearer apart of the section been zoom in to see the velocity profile of the flow. The velocity profile within the orange box is shown in Figure 5.5.

The velocity profile on Figure 5.5 shows the distribution of velocity at the wall of the cyclone filter. Noted that the velocity profile is been interpreted from the fluent software.

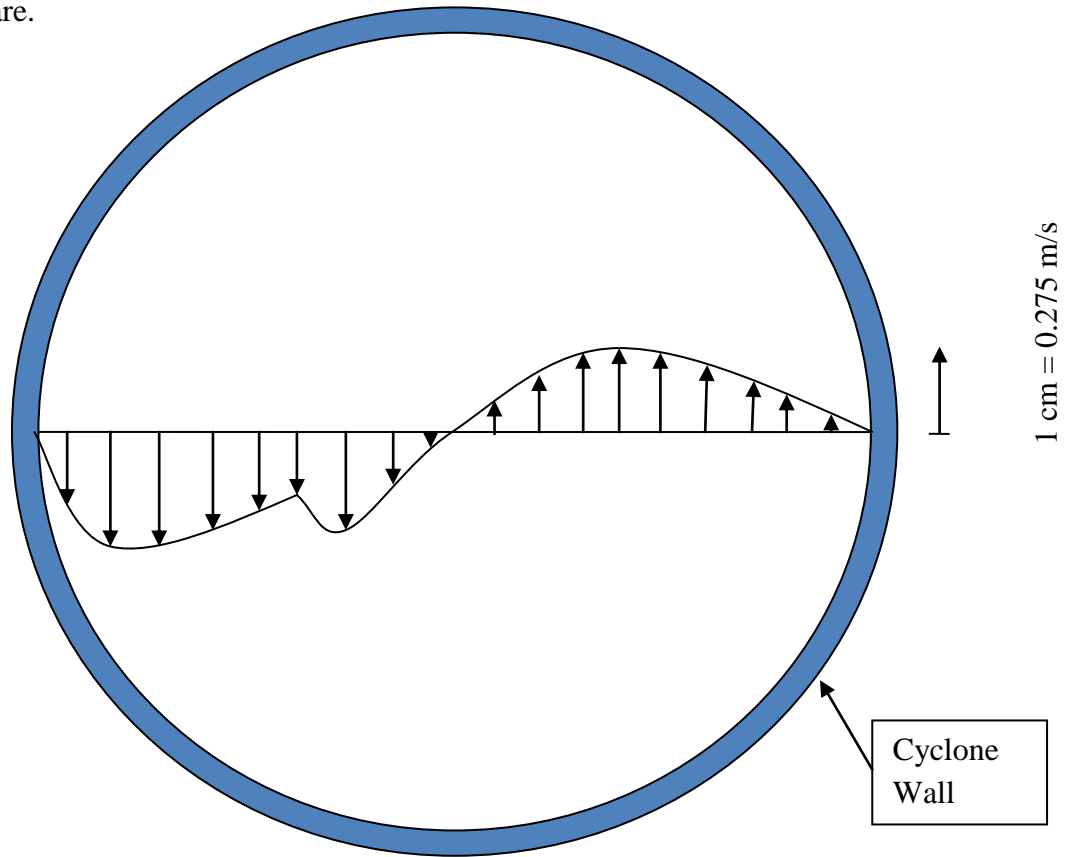


Figure 5.5: Velocity profile of middle horizontal cross sectional of cyclone filter

In Figure 5.5 the velocity profile shows the basic velocity profile that had been drawn base on the Figure 5.4 where been highlighted in orange. In this figure it is shown that at the wall the velocity of the flow will become zero. This is due to the friction from the wall and also non slip condition. At the left side of the velocity profile it is shown that an irregularity of the flow because of the changing of direction of the flow from axial flow to radial flow and also shows the swirl of flow in the filter.

### 5.1.3 Bottom Section

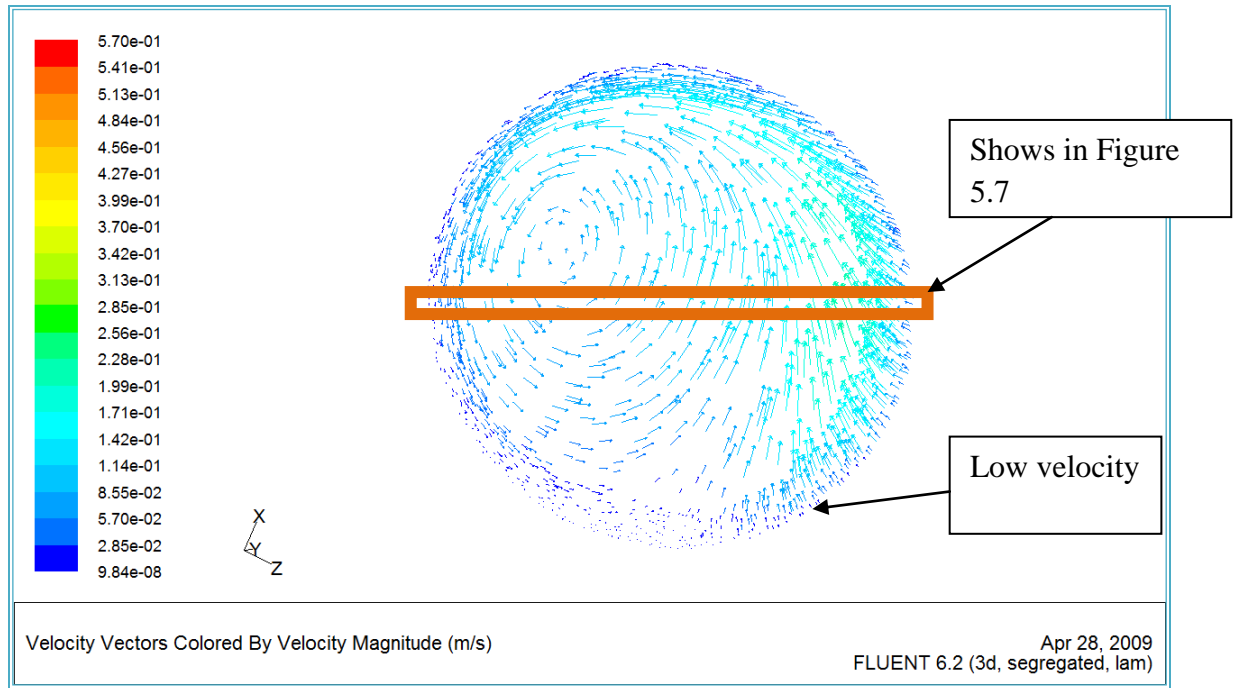


Figure 5.6: Horizontal bottom cross sectional cutting of cyclone filter

Figure 5.6 shows that the cross section of the bottom section of the bottom section of the filter. The Figure shows that the range of the velocity is between 0 and 0.142 m/s. The velocity range in this section are become lessen compare to the previous cross sectional area. In this section the quantity of the low velocity flow are more therefore the quantity of dust and also ash to be in the settling state increase. Logically there will be more dust and ash will be collected in the settling tank as the flow goes lower to the filter.

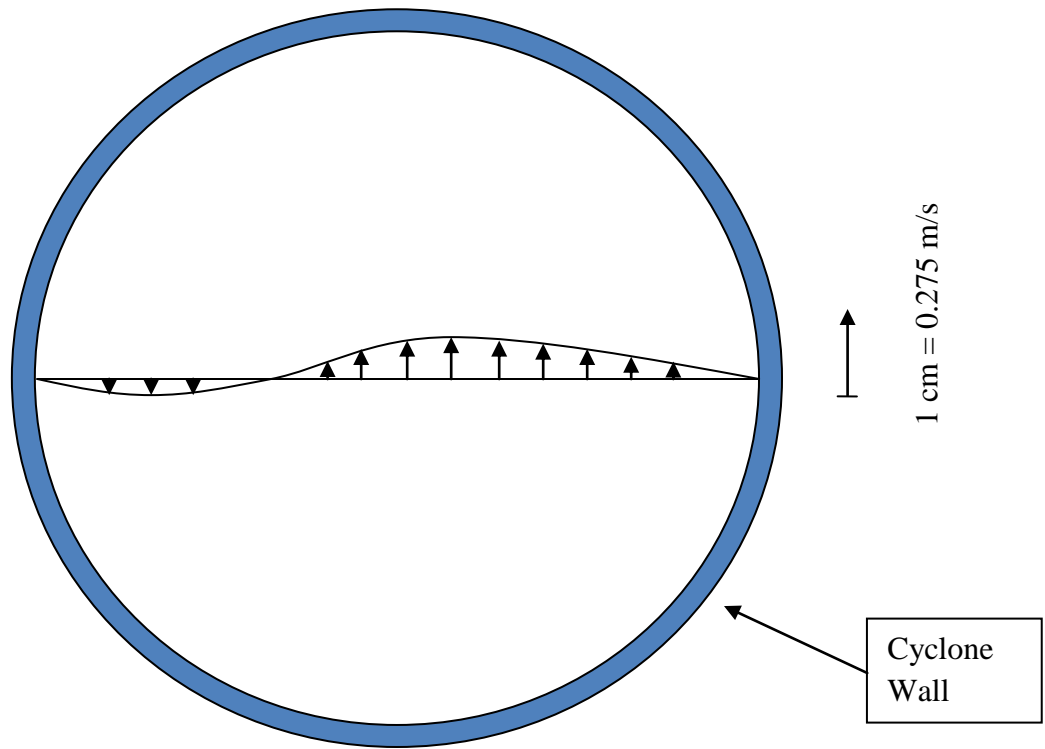


Figure 5.7: Velocity profile of bottom horizontal cross section of cyclone filter

Figure 5.7 shows that the velocity profile of highlighted at Figure 5.6 in orange. In the Figure 5.7 it is shown that the velocity profile for this part is no longer symmetrical with the vertical axis of the cyclone. This is because of the effect of the cyclone filter itself, of which its purpose is to create swirl effect along the filter. The swirl effect will make the flow move downwards which reduces the flow velocity.

### 5.1.4 Velocity Vectors within the Cyclone

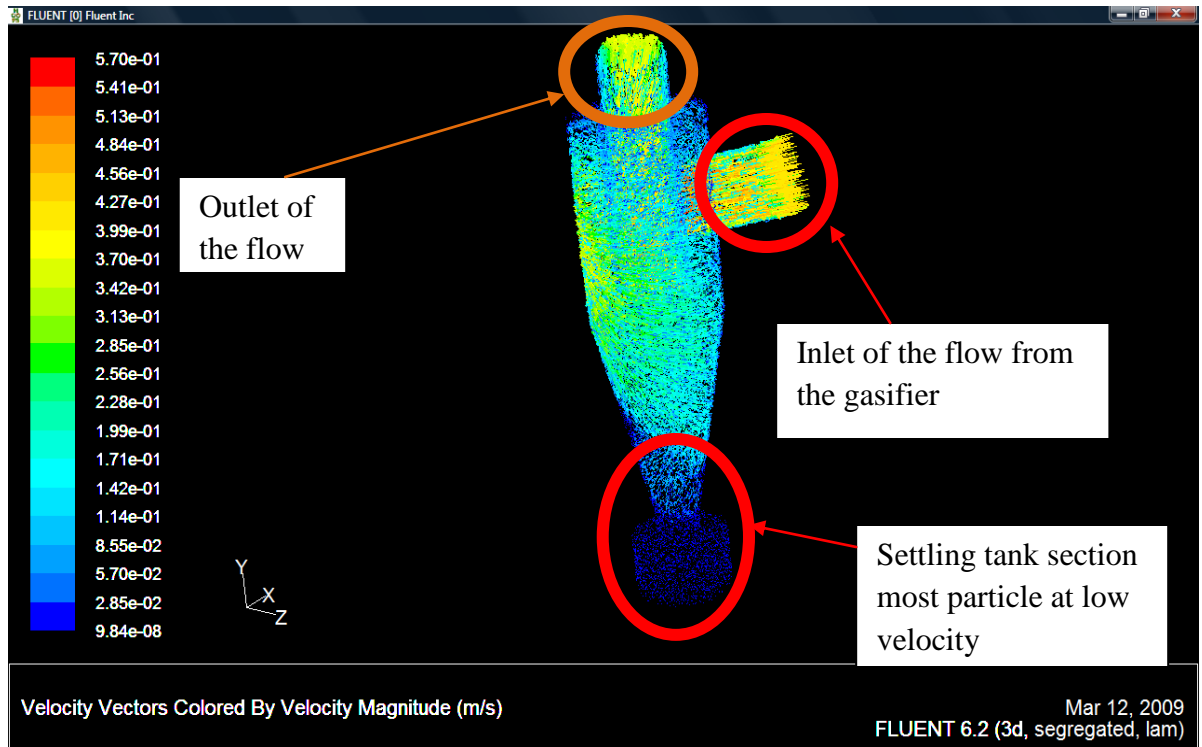


Figure 5.8: Velocity Vector of fluid in the cyclone filter.

Figure 5.8 shows the velocity vector of the flow in the cyclone. It is shown that in the settling tank area the velocity of the particle is between  $2.85 \times 10^{-2}$  and  $9.84 \times 10^{-8}$  m/s. In the calculation part (settling velocity) it shows that both dust and also ash content have settling velocities of  $2.2328 \times 10^{-7}$  m/s and  $3.6077 \times 10^{-4}$  m/s, respectively. This shows that in the simulation, the cyclone filter have the range of the velocity flow where within this range the velocity of the fluid definitely reach the settling velocity of the dust and ash.

### 5.1.5 Velocity Contours

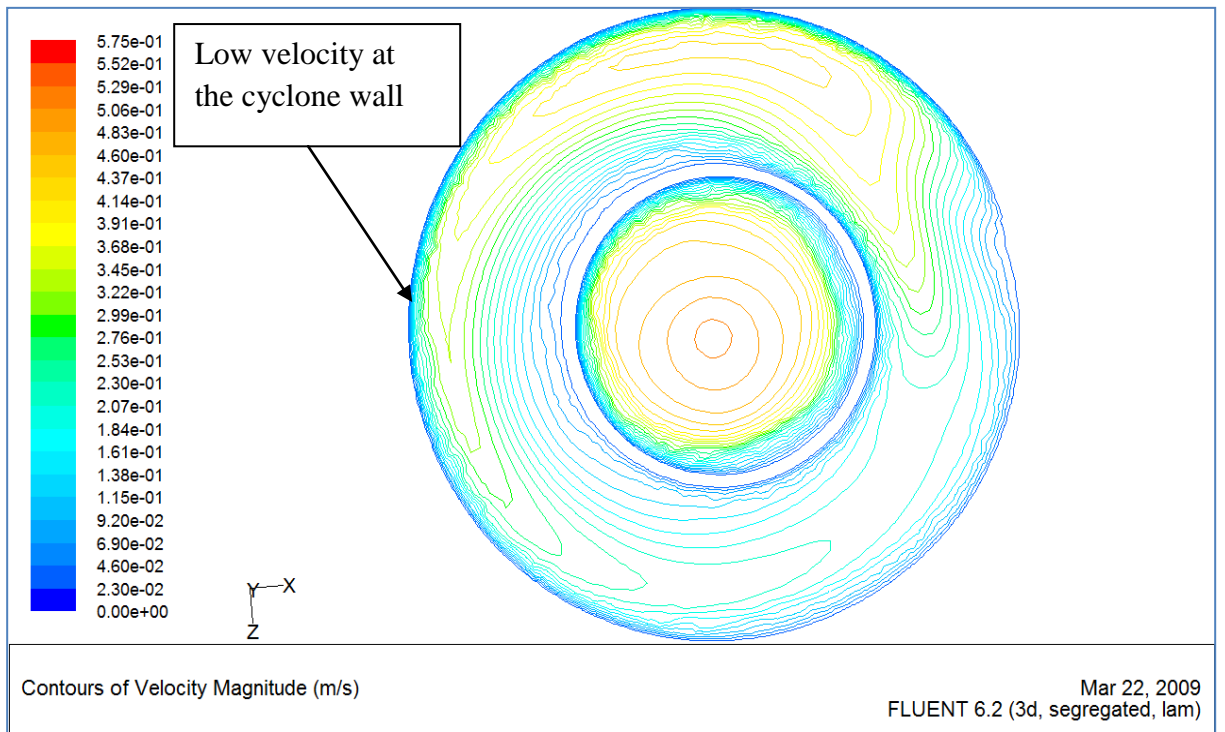


Figure 5.9: Contours of the velocity magnitude of horizontal cut in cyclone filter

Figure 5.9 shows the contours of the velocity magnitude of horizontal cut in cyclone filter. As the contours show the distribution of the various velocity profile it is clear that the contours show that the velocity of the flow is reducing as it gets closer to the wall of the cyclone filter and finally zero when it gains contact with the wall.

### 5.1.6 Flow Path Line



Figure 5.10: Flow path line in the cyclone filter

Figure 5.10 shows the path of the fluid flow in the cyclone filter. The Figure shows that the path of the fluid enters the filter in several lines. This indicates the velocity of the fluid in the particular position. At the inlet of the filter we can identify the highest velocity of the flow are located at the center of the inlet path. In the figure the study of the flow also can be learn and identify. It is learned that the behavior of the fluid during the process it is not always in smooth condition. Where else the fluid tends to go down due to the gravity and then went back up at the outlet. The swirl that had been look in the figure, are the primary affect that that will contribute to the filter concept which is the inertia and the settling velocity.

## 5.2 Testing

Testing of gasifier and filter:

The testing are been done between block 18 and 19. The gasifier had been run for about half an hour before it is been tested. The effectiveness of the filter are been tested by simply putting the fabric filter that had a filter rating of 20  $\mu\text{m}$ . This is to identify that the cyclone filter actually filter out the particulate bigger than 20  $\mu\text{m}$  (ash and dust). The method and procedure of testing are been explain in Chapter 3. The filter are been put in two opening which are been shown in Figure 5.11.

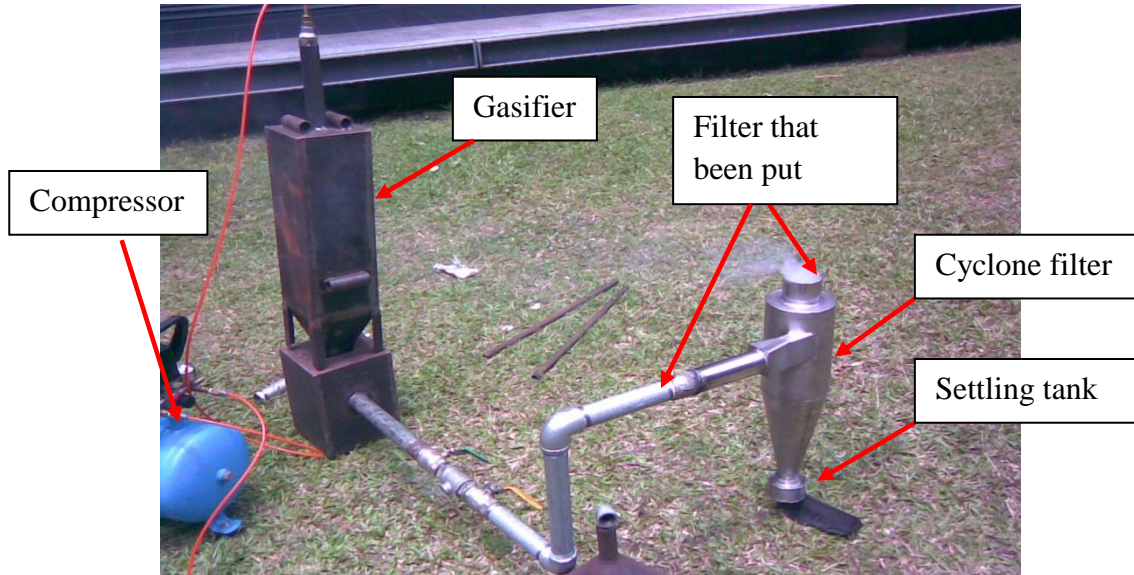


Figure 5.11: Testing of filter

The fabric filter was weight before and after the testing. This is to determine the amount (weight) of the particulate been capture by the filter. The data are been collected in table form that been shown in Table 5.1.



Figure 5.12 shows the settling tank with the particulates collected. In the testing it shows that the filter are filtering the particulate but the effectiveness of it are base on the data collected in Table 5.1. The particulates collected at the settling tank are the results of inertia and settling velocity, as explained in Chapter 2. It is observed that the particulates collected in the settling tank are ash and also some fine dust.



Figure 5.12: Settling tank and particulate collected

Table 5.1 shows the data collected during the test of the filter. There are 2 main sections highlighted, which are the data before and after the filter. At first the fabric filter had been weight to get the initial weight. After the testing the fabric filter been weight again, the difference in weight is the weight of capture particulate. The data from Table 5.1 been tabulated into graph form as shown in Figure 5.13.

Table 5.1: Result from Filter testing

Reading	Velocity inlet (m/s)	Velocity outlet (m/s)	Before filter			After filter		
			Weight before testing (gram)	Weight after testing (gram)	Weight of product (gram)	Weight before testing (gram)	Weight after testing (gram)	Weight of the product (gram)
1	0.045	0.023	0.6648	0.8532	0.1884	0.7071	0.7425	0.0354
2	0.039	0.034	0.6648	0.8503	0.1855	0.7071	0.7433	0.0362
3	0.048	0.039	0.6968	0.8803	0.1835	0.7137	0.7468	0.0331
4	0.041	0.037	0.6968	0.8877	0.1909	0.7137	0.7457	0.032
Average	0.04325	0.03325	-	-	0.1871	-	-	0.0342

In Figure 5.13 it is clearly shows the difference of weight between after filter and before the filter. There are 5 reading including the average in the Figure 5.13.

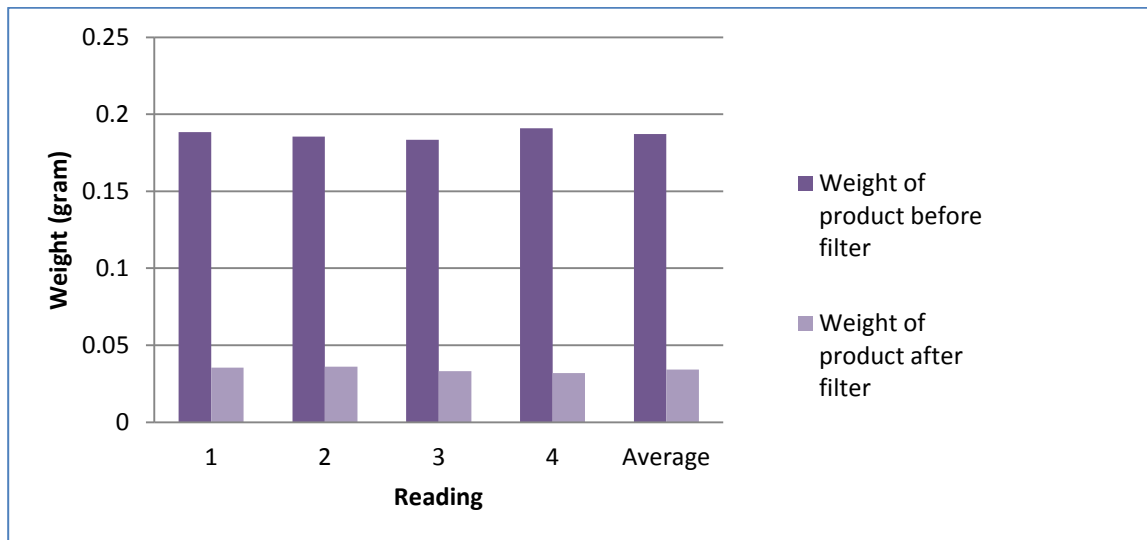


Figure 5.13: Comparison of weight

### **Effectiveness of Filter**

The effectiveness or the efficiency of the filter is given as ;

$$\begin{aligned}\text{Effectiveness} &= 1 - \frac{\text{Average weight of product after filter}}{\text{Average weight of product before filter}} & (2.11) \\ &= 1 - \frac{0.0342}{0.1871} \\ &= 0.8172 = 81.72\%\end{aligned}$$

From the calculation it is shown that the effectiveness of the filter is 81.72%. Therefore the use of the filter can be implemented in the gasifier to filter out the particulate that are larger than 20 $\mu$ m. But the system will also need secondary filter to eliminate the possibility of the particles to be in the combustion engine.

## CHAPTER 6

### CONCLUSIONS AND RECOMMENDATIONS

In conclusion there are many considerations needed to be taken into account to fabricate the filter. It is generally known that the syngas released from the gasifier will cause the short life span of the combustion engine if not filtered. The syngas contain water vapor, dust, ash and tar. In this report the filter that had be design and fabricate are the preliminary filter whereby it will filter bigger product. If the filter been implemented to the system it will eliminate 2 major causes of failure which is the occurring of slag and clogging in the internal combustion engine. The cyclone filter that had been fabricated is from stainless steel. This material been chosen base on the availability to manufacturer, the melting point above the safety factor and also to consider coating because of the existent of water vapor and tar. In Chapter 5, the simulation of flow shows that the design cyclone filter is able to filter dust, ash and other particulates that are 20  $\mu\text{m}$  or bigger in size. This is when the velocity variation in the filter matches with the settling velocity of ash and dust. There is also a need to place another filter to clean out other product that is smaller than 20  $\mu\text{m}$ . The next filter will then filter the other two products that will shorten the life of the combustion engine which is water vapor and tar.

In the testing of the cyclone filter it is verified that, the effectiveness of the filter are 81.7%, there are possibility for the particulate to escape or pass through the filter. Therefore there is a need to introduce another filter in order to eliminate this problem. It must be noted that the filter only filter out particulate that are 20  $\mu\text{m}$  or larger in size which will only filter ash and dust. Filtering of two other major components of the gasifier product, which are water vapor and tar, would be necessary. Cooling of produce gas are also recommended since it will increase the energy density (Kaupp, 1982) and will be easier to filter out water vapor when the temperature of the produce gas is lowered. When the temperatures of produce gas are reduced the variation of filter that can be implement will be increased due to the temperature factor. The validation of CFD result with experiment should be carried out.

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Appendix A-1 Material Properties of Metal (Ress, 2009)

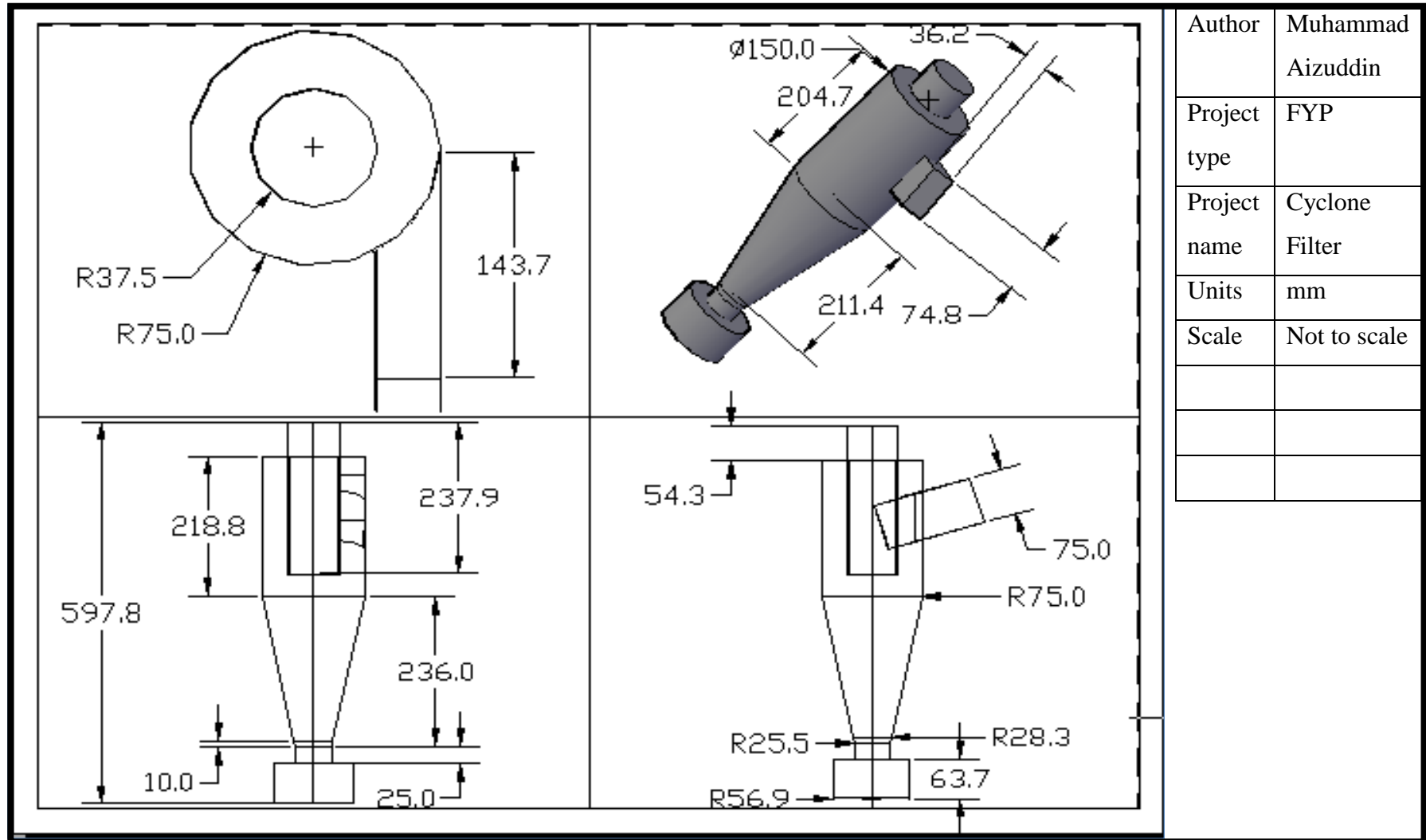
<b>Elements</b>	<b>Symbol</b>	<b>Melting Point Celsius</b>	<b>Melting Point Fahrenheit</b>
Aluminum	Al	659	1218
Brass (85 Cu 15 Zn)	Cu+Zn	900-940	1652-1724
Bronze (90 Cu 10 Sn)	Cu+Sn	850-1000	1562-832
Cast Iron	C+Si+Mn+Fe	1260	2300
Carbon	C	3600	6512
Chromium	Cr	1615	3034
Copper	Cu	1083	1981
Gold	Au	1063	1946
Hydrogen	H	-259	-434.2
Inconel	Ni+Cr+Fe	1393	2540
Iron	Fe	1530	2786
Lead	Pb	327	621
Magnesium	Mg	670	1240
Manganese	Mn	1260	2300
Monel	Ni+Cu+Si	1301	2400
Nickel	Ni	1452	2646
Phosphorous	P	44	111
Silicon	Si	1420	2588
Silver	Ag	961	1762
Stainless Steel	Cr+Ni+Mn+C	1363	2550
Steel-High Carbon	Cr+Ni+Mn+C	1353	2500
Medium Carbon	Cr+Ni+Mn+C	1427	2600
Low Carbon	Cr+Ni+Mn+C	1464	2700
Tin	Sn	232	450
Titanium	Ti	1795	3263
Tungsten	W	3000	5432
Zinc	Zn	419	786





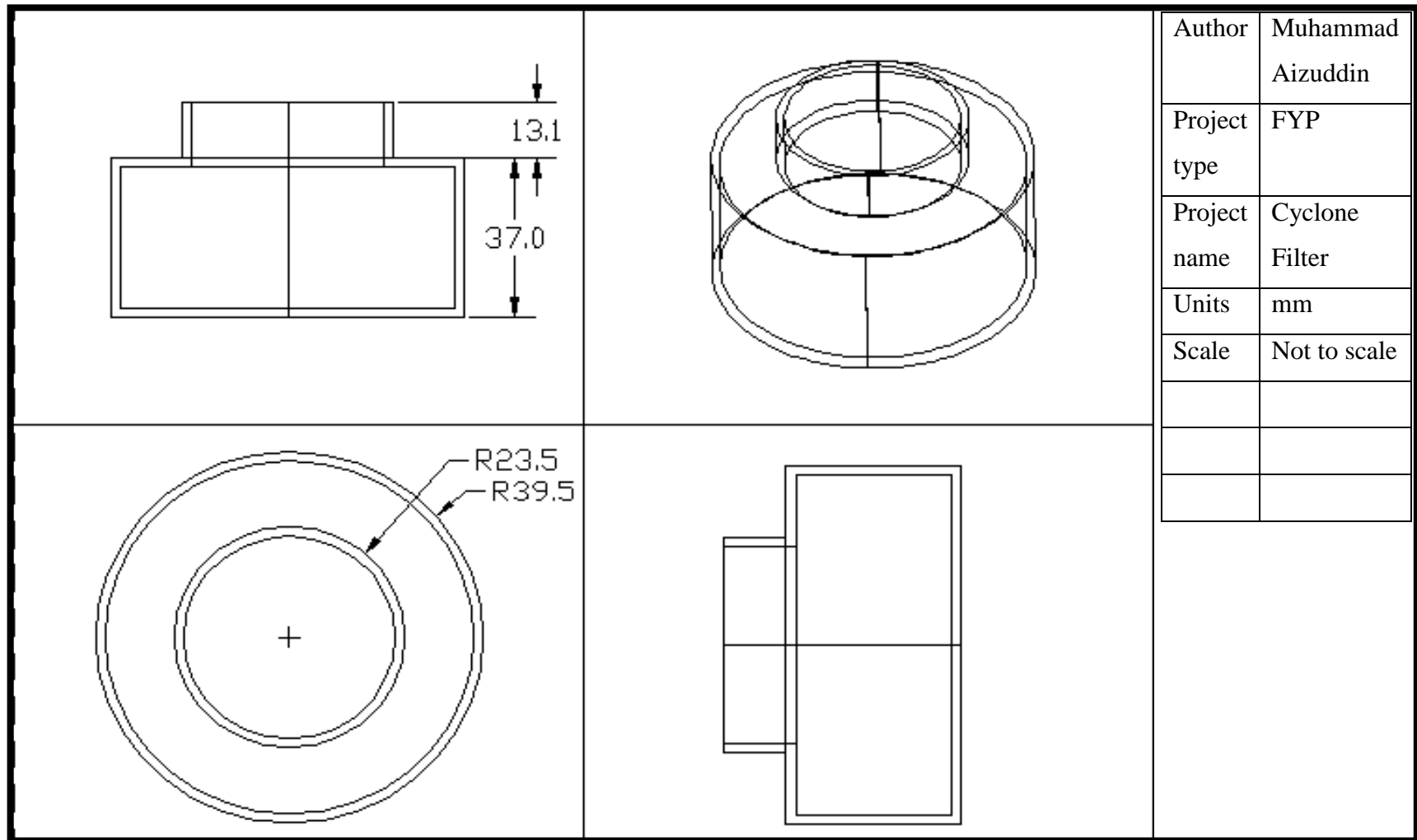


# Appendix A-4 Cyclone design using AutoCAD

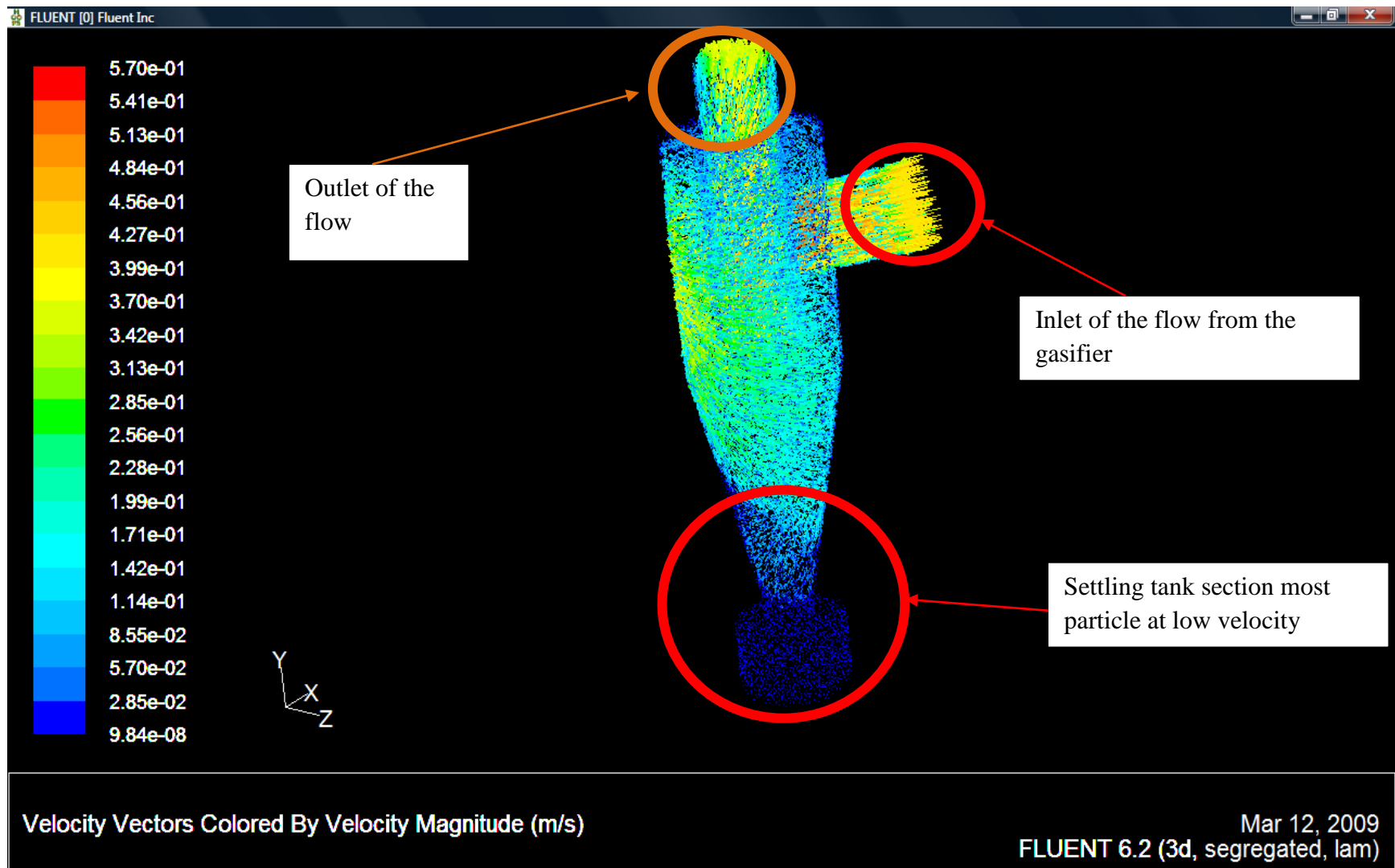


Author	Muhammad Aizuddin
Project type	FYP
Project name	Cyclone Filter
Units	mm
Scale	Not to scale

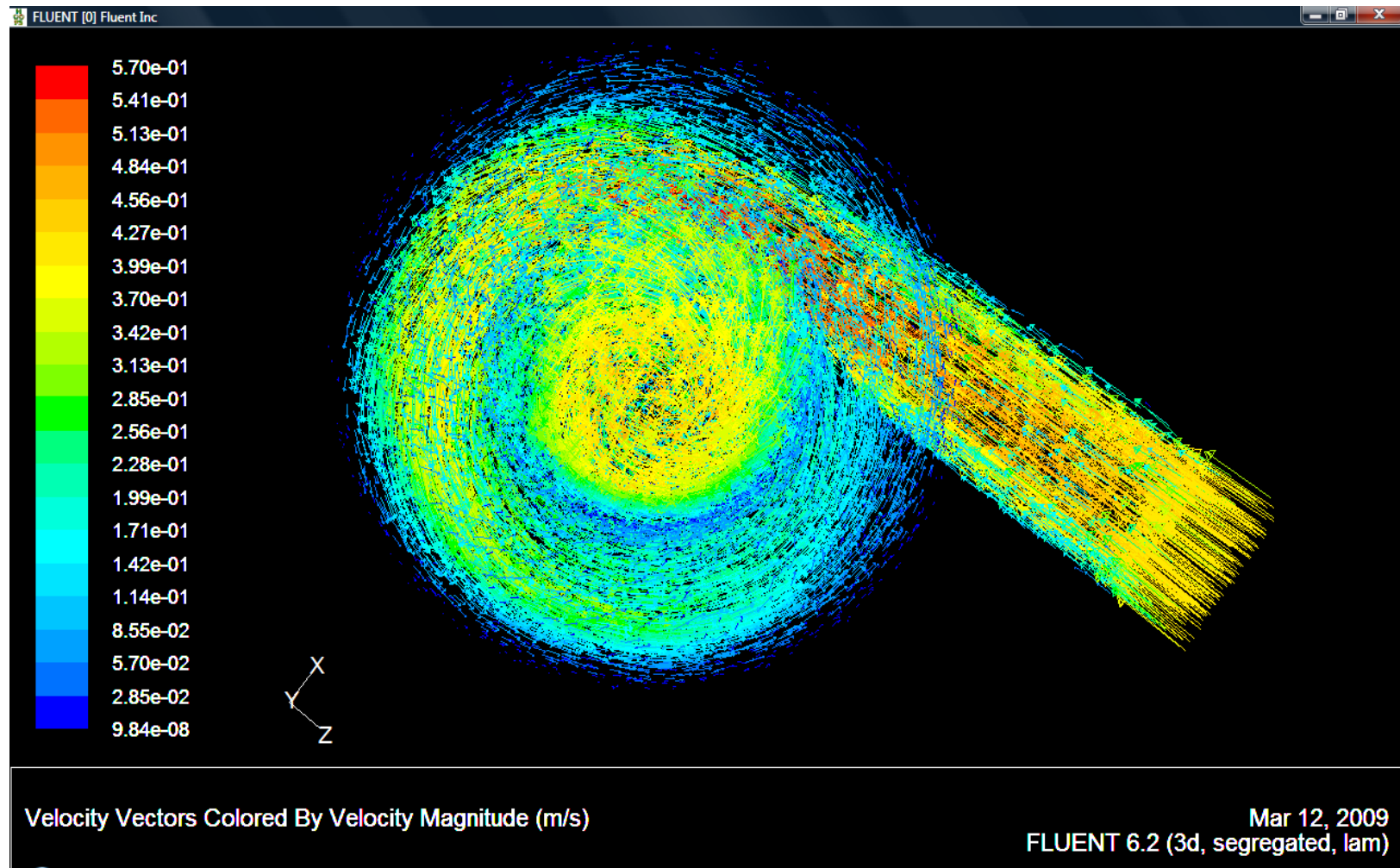
# Appendix A-5 Settling tank design using AutoCAD



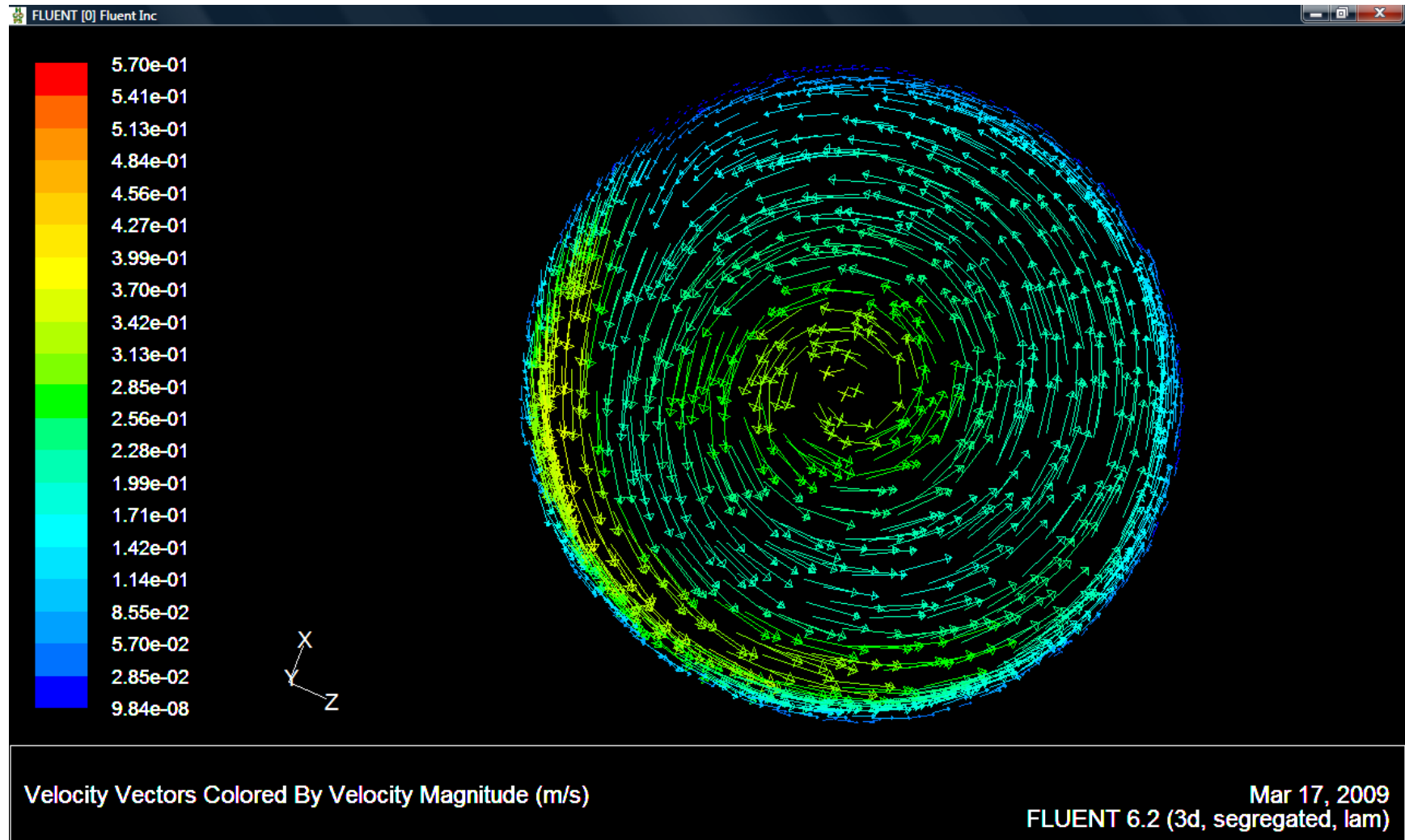
# Appendix A-5 Velocity Colored by Velocity Magnitude (Front view)



# Appendix A-6 Velocity Colored by Velocity Magnitude (Top view)



Appendix A- 7 Velocity Colored by Velocity Magnitude (Middle Cross sectional)



# Appendix A-8: Flow Path Line in the Cyclone Filter

